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(54) A micro relay device having a membrane with slits

(57) The invention relates to an improved design for micro relays comprising a membrane 1 with slits 2 defining suspension beams 3 and actuation portions 4. Large areas of actuation portions 4 can be combined with small elastic constants of suspension beams 3 in order to improve the contact forces.

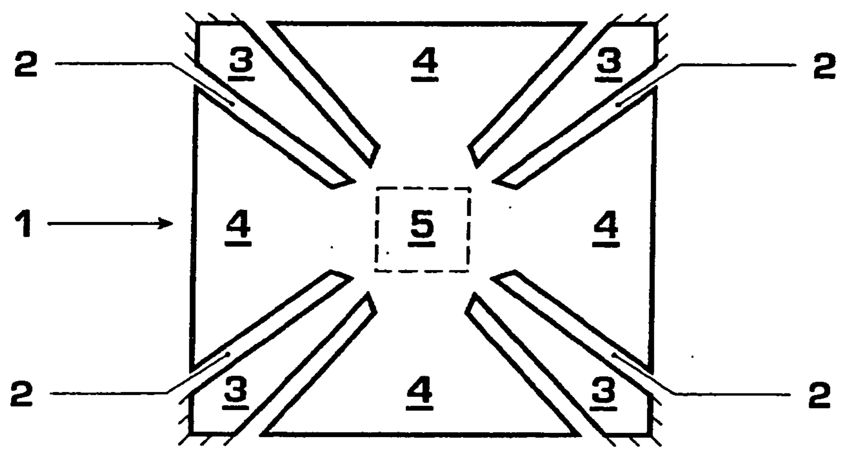

Fig. 1

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Description

Technical field

[0001] This invention relates to micro relays. The term micro relay is used for microscopic electric switches in which a movable contact piece and a further contact piece can be brought into and out of contact with each other. The movable contact piece is driven by an electrostatic, electromagnetic, piezoelectric or an alternative drive mechanism. The term micro relay can be explained in that these switches resemble conventional relays but are much smaller and usually produced by means of techniques similar to those of semiconductor technology and/or micro technology. Very often, micro relays are realized in Si-based technologies.

[0002] The present invention relates to a micro relay with a new improved structure. This micro relay has an electrostatic drive, i.e. a drive by means of an electric capacitor.

Prior art

[0003] Micro relays with electrostatic drives and having a movable first contact piece and a second contact piece for switching operation are known. The movable contact piece is supported in an elastic manner and connected to one actuation electrode of the electrostatic drive. An electrostatic force between this first actuation electrode and a second actuation electrode is used to deform the elastic support in order to move the first contact piece to close and open the micro relay.

[0004] The electrostatic type drive has the advantage of a low actuation power, however, the disadvantage of comparatively small closing forces between the contact pieces. This applies namely to so-called wedge-type micro relays in which the movable contact piece is fixed at the end of a bent silicon beam. This silicon beam constitutes the first actuation electrode whereas the second actuation electrode is located on the substrate that also carries the second contact piece. Applying a driving voltage between the actuation electrodes leads to an unrolling of the bent silicon beam so that an air wedge between this beam and the substrate reduces and moves towards the beam end until the contact pieces come into contact with each other. In this micro relay, the silicon beam constitutes the elastic support of the first contact piece as well as the first actuation electrode.

Summary of the invention

[0005] The object of the present invention is to provide an improved structure of a micro relay device with electrostatic drive.

[0006] According to the invention, a micro relay device comprises:

- a substrate;
- a membrane mounted on said substrate and being essentially parallel to said substrate,
  said membrane having at least one slit,
  said slit starting from a peripheral border of said membrane and defining a deformable suspension beam being part of said membrane,
  said membrane further comprising an actuation portion carrying a first actuation electrode for electrostatic actuation and being separated from said suspension beam by said slit and being connected to said suspension beam at an end of said slit,
  said membrane carrying a first contact piece for switching operation;

said micro relay device further comprising:

- a second contact piece for cooperating with said first contact piece; and
- a second actuation electrode for cooperating with said first actuation electrode;
  said actuation electrodes being adapted to deform said suspension beam as a result of an electrostatic actuation force, so that said first contact piece can be moved essentially perpendicular to said substrate to come into contact with and to be separated from said second contact piece.

[0007] Further, the invention relates to embodiments of said micro relay device as defined in the dependent claims. Finally, the invention also relates to a method for producing such micro relay devices as defined in claim 10.

[0008] According to the invention, instead of a flexible beam carrying the first movable contact piece as well as the first actuation electrode, a membrane is used. This membrane is mounted on the substrate and includes a slit defining at least one suspension beam for mounting the membrane. The slit has the function to allow a deformation of the suspension beam that is independent from the membrane. E.g. the suspension beam could be defined between said slit and a peripheral border of the membrane or between two such slits.

[0009] Further, the membrane comprises a portion that is used for actuation and thus carries the first actuation electrode. Also the actuation portion is adjacent to said slit and separated from said suspension beam by the slit. Thus, the actuation portion and the suspension beam are connected with each other at an end of the slit. Applying an actuation voltage creates an electrostatic force between the first actuation electrode and a second actuation electrode that is also a part of the micro relay device. This actuation force is applied to the first actuation electrode and thus to the actuation portion. The slit already described allows the suspension beam to be flexed independently from the actuation portion so that the suspension beam serves as the elastic suspension.

[0010] Consequently, the micro relay device compris-

es a first and a second contact piece wherein the first contact piece is movable and carried by the membrane. It is clear that the first contact piece should not be arranged at or near that end of the suspension beam that is mounted to the substrate. The first contact piece could be arranged at another part of the suspension beam or, preferably, at a part of the actuation portion or another part of the membrane moving with the actuation portion. Thus, by applying an electrostatic force by means of the actuation electrodes, the movable first contact piece can be moved along with an elastic deformation of the suspension beam. The second contact piece is arranged in a manner that allows a closing and opening switching operation by a movement of a first contact piece into and away from an electric contact to the second contact piece.

[0011] The micro relay device according to the invention is improved compared to the above described prior art in that the actuation portion and the suspension beam can be designed and optimised independently from each other. It is merely necessary that they are connected to each other at the end of the slit. However, they are not combined in one and the same flexible beam as in the prior art. Further, according to the slit membrane design, it is possible to use comparatively long suspension beams and also activation portions of a comparatively large area without increasing the overall size and length of the micro relay device too much. This is due to the fact that both are separated from each other by the slit which can be relatively narrow. Thus, the complete design can be very compact and economical as regards the substrate area occupied.

[0012] By using not too short suspension beams, small elasticity constants of the suspension beam can be realized without using too thin and thus delicate membrane thicknesses. Further, the suspension beam can be very narrow for similar reasons. However, in contrast to the prior art, the actuation portion can be much broader in order to increase the active area of the actuation electrodes. In the conventional design described above, the width of the beam was constant so that a broad beam increasing the electrode area simultaneously increased the elasticity constant of the elastic suspension. Thus, with the conventional design, the only means to combine relatively large electrostatic forces with not too large elasticity constants are very thin material and/or a substantial length of the beam in total. However, beams being too long are not economical with regard to the substrate area and thus to the costs of the micro relay device.

[0013] Finally, the invention allows to take advantage of elastic properties also of the actuation portion that can be completely different from those of the suspension beam, as explained below.

[0014] In summary, the invention allows an individual optimisation of the actuation portion and the suspension beam independently from each other since they are "decoupled" and not combined. On the other hand, by using a slit membrane, the overall technology remains very simple.

[0015] In a preferred version, the first contact piece is arranged neither at the suspension beam nor at the actuation portion but at that part of the membrane connecting both. Thus, the contact piece is near the end of the slit. In this way, the complete actuation portion can be used for the actuation electrode. Further, its elasticity properties can be taken advantage of as explained below.

[0016] Namely, since the actuation portion is a part of the membrane, it will be elastic in some sense in most cases. If the elasticity constant with regard to a flexing movement in the direction perpendicular to the substrate (as for the suspension beam) is higher than that of the suspension beam but still small enough to be able to be flexed by the electrostatic forces, it can be used to increase the closing force of the contact pieces by choosing a design in which during a closing movement the contact pieces contact first and afterwards the actuation area can be moved and flexed still further, e.g. until the actuation electrodes contact each other. Thus, relatively high deformation forces of the actuation portion act as contact forces for the closed contact of the micro relay.

[0017] A preferred way to achieve adequate elasticity constants is by choosing adequate widths of the suspension beam and the actuation portion whereas the membrane thickness is constant. This allows a very simple technology in which the elasticity design can be done by the two-dimensional design of the membrane, e.g. by the slit structure and the form of the membrane. It is referred to the embodiments for illustration.

[0018] In order to achieve the above-described effect of increased closing force by means of flexing of the actuation portion, it is preferred to mount the second contact piece on the substrate in an elevated position compared to the second actuation electrodes. Here, elevation is to be understood in the sense of the movement perpendicular to the substrate. Compare the embodiments below.

[0019] According to a further preferred version of the invention, the membrane is flat as long as the actuation electrodes are voltage-free. Thus, the actuation forces are used to deform the membrane from the flat condition into a flexed condition. Again, reference is made to the embodiments.

[0020] Preferred designs of the invention comprise at least two suspension beams and at least two actuation portions. Further, at least four slits are preferred in order to allow a symmetric structure of the complete membrane. Thus, two respective slits define one respective suspension beam and separate it from two respective actuation portions. Two examples are shown as embodiments below.

[0021] A membrane can be made of semiconducting material, e.g. Si. This allows using doped semiconducting regions as conducting paths and thus for wiring the

first actuation electrode and the first contact piece. The actuation electrode itself can also be implemented by means of doped semiconducting regions. The first contact piece itself should preferably be made of metal or at least be metal-coated.

[0022] Of course, also insulating or metal membranes could be used. Insulating membranes could be manufactured of SiO_2 or Si_3N_4 or other materials. Wiring and electrodes on the membrane could be implemented by metal conducting paths-even on semiconducting membranes in order to increase the conductivity. Si can be a preferred material for merely mechanical reasons and could be covered e.g. by an insulating surface layer.

[0023] In order to optimise the suspension beam and the actuation portion or two or more suspension beams and two or more actuation portions, it is preferred to use a much larger area ratio of the membrane for the actuation portion than for the suspension beam (or a multitude of them) in order to increase the electrostatic forces and to decrease the electricity constants of the suspension beams. This goes along with the above mentioned increased width of the actuation portion compared to the suspension beam in view of a higher elasticity constant of the former compared to the latter.

[0024] A preferred manufacturing step for producing a flat membrane being fixed to the substrate at predetermined locations and freely supported over the substrate in its remaining parts, is to use an Si-substrate and an Si-membrane and removing a buried oxide under the membrane, e.g. by chemical means (liquid etching or reactive ion etching or the like).

[0025] However, manufacturing by buried oxide etching could be limited in view of the device height. Especially for power switching it can be preferred to produce the membrane separately, e.g. by back-etching of a separate wafer in order to arrive at a thin Si-membrane or a surface SiO_2 or Si_3N_4 membrane. The membrane could be structured before or after etching of the wafer. A substrate of the device could also be insulating (i.e. glass or oxide surface). The second contact piece and actuation electrodes could be electro-plated by standard processes in order to arrive at high contact pieces. Such standard processes could work with moulds made with standard optical lithography in order to arrive at high aspect ratio electroplated microstructures ("HARM", high aspect ratio microstructures). Another example are LIGA-processes using X-ray lithography with highly collimated synchrotron sources. Also connecting leads going through the substrate are feasible. The membrane could be bonded to mounting posts on the substrate.

Description of preferred embodiments

[0026] In the following, three illustrative embodiments of the invention are shown. They are not intended to narrow the scope of the claims but rather to support the understanding of the technical concept by means of concrete examples. Features disclosed in the embodiments can also be preferred in other combinations.

Figure 1 shows a first embodiment in top view;

figure 2 shows a second embodiment in top view;

figure 3 shows a section through the first embodiment; whereas

figure 4 shows a section through a similar third embodiment.

[0027] Figure 1 shows a top view onto a first embodiment of the invention. Shown is an Si-membrane having a square shape and eight slits 2 in total being arranged in pairs in which slits 2 are spaced from each other. Each pair starts from the peripheral border of membrane 1 near one corner; one of the slits 2 in each pair on each side of each corner; and extends essentially in a diagonal direction for approximately two thirds of the distance to the centre of membrane 1. Thus, each pair of slits 2 defines one respective suspension beam 3.

[0028] Each suspension beam 3 is fixed to an elevated structure on the substrate and thus to the substrate itself as will become apparent from the explanation of figure 3.

Between one respective slit 2 defining one suspension beam 3 and a next neighbour slit 2 defining another suspension beam 3, a respective actuation portion 4 is defined. Thus, membrane 1 of figure 1 comprises eight slits 2, four suspension beams 3 and four actuation portions 4. Between opposed suspension beams 3 and between opposed actuation portions 4 as well as between the ends of slits 2, and in the centre of the square form of membrane 1, a contact portion 5 is situated. Contact portion 5 carries a first contact piece, which is symbolized by the sketched line in figure 1. The contact piece is a metallized part of the lower side of membrane 1. This contact piece is contacted over metal wiring on suspension beams 3, contact piece and wiring being coated on an SiO_2-layer of membrane 1. Details are not shown. Further, actuation portions 4 comprise similar metal areas over essentially their complete area in order to serve as first actuation electrodes.

[0029] An alternative membrane design is shown in figure 2. Identical reference numerals are used for corresponding parts. The differences to the first embodiment of figure 1 are the circular shape of membrane 1 and the threefold symmetry of its structure compared to the fourfold symmetry of figure 1. I. e. there are three pairs of two respective slits 2 (under 120° instead of 90° in figure 1). Thus, there are three suspension beams 3 and three actuation portions 4. Again, the centre area is used as contact portion 5.

[0030] It is apparent that in both designs the overall design is highly symmetrical and comprises actuation portions 4 constituting the main part of the overall area of membrane 1. Further, actuation portions 4 are much

broader than suspension beams 3. Since membranes 1 have a substantially constant thickness, the elastic properties of actuation portions and suspension beams 3 are different from each other.

[0031] Figures 3 and 4 show sections illustrating the function of such membrane designs. Figure 3 is a section through the design of figure 1 along a diagonal section line, i.e. through opposed suspension beams 3. However, figure 3 also shows the sectional form of actuation portions 4. Figure 4 shows an alternative structure as a third embodiment.

Suspension beams 3 are fixed to elevated parts of the substrate (with reference numeral 6 in figure 3 and 4). These elevated parts are not shown in detail but can be parts of substrate 6 that are used to mount a free membrane 1 over substrate 6.

[0032] Substrate 6 carries a second contact piece 7 which is pressed against the first contact piece on the lower side of contact portion 5 of membrane 1 in figure 3 and figure 4. Figures 3 and 4 show two different versions of second contact pieces 7 which can be unitary closed structures as in figure 4 or structures with a centre opening as in figure 3. Figure 3 also suggests that the micro relays shown in the embodiments could further be used for multiple switches by using multiple first and multiple second contact pieces and adequate wiring structures.

[0033] Substrate 6 further comprises second actuation electrodes 8 being electroplated regions at those locations on which actuation portions 4 are pressed down in figures 3 and 4.

[0034] Bearing in mind that membrane 1 is flat as long as the actuation electrodes are voltage-free, the function is as follows: Applying a voltage between the first actuation electrodes within actuation portions 4 and second actuation electrodes 8 produces an attractive electrostatic force between these parts. Since actuation portions 4 are much stiffer than suspension beams 3, membrane 1 lowers mainly by means of a flexing deformation of suspension beams 3 until contact portion 5 touches second contact piece 7. Since second contact piece 7 is somewhat elevated compared to second actuation electrodes 8 on substrate 6, the above-mentioned attractive force now tends to deform actuation portions 4 until they touch substrate 6. A short circuit between the actuation electrodes can be prevented by oxide layers or the like.

[0035] The relatively high elastic constants of actuation portions 4 provide for a comparatively large closing force of the micro relay. On the other hand, the beginning of the closing movement is determined by the relatively small elastic constants of suspension beams 3, which is imported because of the small electrostatic forces in case of larger distances between the actuation electrodes. However, when the deformation of actuation portion 4 takes place, the distance between the actuation electrodes is already smaller and thus the attractive forces are much higher. (In a parallel plate capacitor, the attractive force is inversely proportional to the square of the plate distance.) The initial distance (with flat membrane 1) between the contact pieces is important for the voltage withstand capacity of the micro relay. (Thus, the elevation of second contact pieces 7 will not be very high, usually.) Please note that figures 3 and 4 are not dimensional, neither in the relations between the different heights nor in the relations between the heights and the widths of the structures shown. Realistic micro relays will be much flatter and broader.

[0036] It is clear that a section through the structure of figure 2 would look very similar to figures 3 and 4 and thus is obsolete here.

[0037] Further, it can be seen that the invention provides very large areas of the actuation electrodes in compact designs allowing small pull-in voltages, and even comparatively long suspension beams 3. The actuation electrode areas and the design of suspension beams 3 can be optimised independently from each other since they are decoupled parts in the membrane design.

[0038] Finally, since even central contact part 5 of membrane 1 is somewhat flexible, it is obvious that during the flexing movement of actuation portions 4, there will also be some deformation of contact portion 5. This results in small lateral movements between the first and second contact pieces which can be of high importance for the improvement of the contact resistances since oxides and other surface layers can be removed and the actual contact area can be increased. It is to be noted that the real electric contact between the contact pieces only takes place at few more or less microscopic points. These microscopic contacts can be enlarged and improved by lateral movements on the contact force because of some plastic deformation of the contact pieces.

[0039] It appears also from figures 1 and 2 that for embodiments in which the elastic constants of the actuation portions are not much higher than those of the suspension beams, it is effectively the sum of the lengths of the suspension beams and the actuation areas (in radial direction) that appears as effective beam length compared to conventional designs. Thus, if the above-explained contact force improvement is not important for a special application, the invention allows compact designs with long effective beam lengths. In those cases, the first contact piece could also be included in the areas of the actuation portions.

[0040] A further important advantage of these embodiments is that an initial curvature of membrane 1 is not required. This simplifies manufacturing substantially.

[0041] Disadvantages can be low natural frequencies because of somewhat larger moved masses and low elastic constants. Thus, preferred applications are in power switching more than in signal switching. However, if the design according to the invention is made small enough, also fast micro relays can be obtained.

Claims

1. A micro relay device comprising:

   - a substrate (6);
   - a membrane (1) being essentially parallel to said substrate (6),

   said membrane (1) having at least one slit (2), said slit (2) starting from a peripheral border of said membrane (1) and defining a deformable suspension beam (3) being part of said membrane (1), said membrane (1) further comprising an actuation portion (4) carrying a first actuation electrode for electrostatic actuation and being separated from said suspension beam (3) by said slit (2) and being connected to said suspension beam (3) at an end of said slit (2), said membrane (1) carrying a first contact piece (5) for switching operation; said micro relay device further comprising:

   - a second contact piece (7) for cooperating with said first contact piece (5); and
   - a second actuation electrode (8) for cooperating with said first actuation electrode (4);

   said actuation electrodes (4, 8) being adapted to deform said suspension beam (3) as a result of an electrostatic actuation force, so that said first contact piece (5) can be moved essentially perpendicular to said substrate (1) to come into contact with and to be separated from said second contact piece (7).

2. A micro relay device according to claim 1, in which said first contact piece is arranged at an area (5) of said membrane (1) connected said suspension beam (3) and said actuation portion (4) and being adjacent to said end of said slit (2).

3. A micro relay device according to claim 1 or 2, in which said actuation portion (4) is deformable and has a higher elasticity constant compared to said suspension beam (3).
   and said micro relay device is arranged to deform said actuation portion (4) by said actuation force of said actuation electrodes (4, 8) after said contact pieces (5, 7) have been brought into contact by deformation of said suspension beam (3), in order to increase a closing force of said contact pieces (5, 7).

4. A micro relay device according to claim 3, in which said actuation portion (4) and said suspension beam (3) have an essentially constant membrane thickness and said actuation portion (4) is broader than said suspension beam (3).

5. A micro relay device according to one of the preceding claims, in which said second contact piece (7) is mounted on said substrate (6) underneath said membrane (1) and is elevated with regard to said second actuation electrodes (4, 8) with respect to said movement of said first contact piece (5).

6. A micro relay device according to one of the preceding claims, in which, if said actuation electrodes (4, 8) are voltage-free, said membrane (1) is flat.

7. A micro relay device according to one of the preceding claims, having at least two of said suspension beams (3), at least two of said actuation portions (4), and at least four of said slits (2),
   said suspension beams (3) each being defined by two respective of said slits (2) and being separated from two respective of said actuation portions (4) by said two respective slits (2).

8. A micro relay device according to claim 2 and 7, in which said area (5), at which said first contact piece is arranged, is situated in a central area of said membrane (1) between said suspension beams (3), said actuation portions (4) and said slits (2).

9. A micro relay device according to one of the preceding claims, in which said actuation portion(s) (4) occupies a substantially larger area ratio of said membrane (1) than said suspension beam(s) (3).

10. A method for producing a micro relay device according one of the preceding claims, in which said membrane (1) is a Si-membrane and said substrate (6) is a Si-substrate
    and producing said micro relay device includes the step of mounting separately produced membrane (1) on said substrate (6).

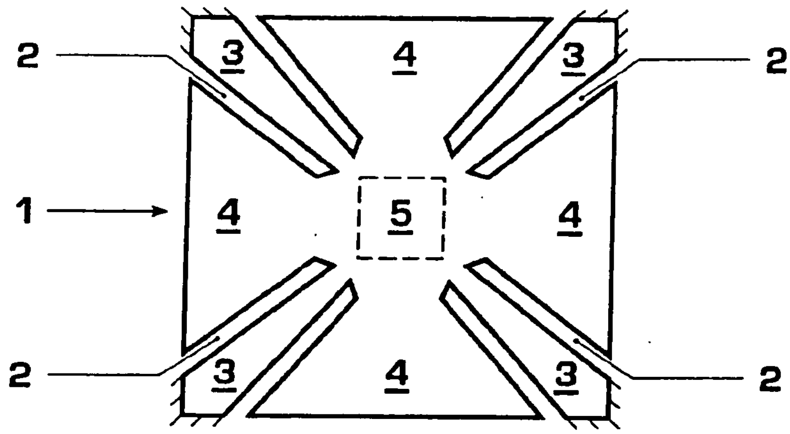

Fig. 1

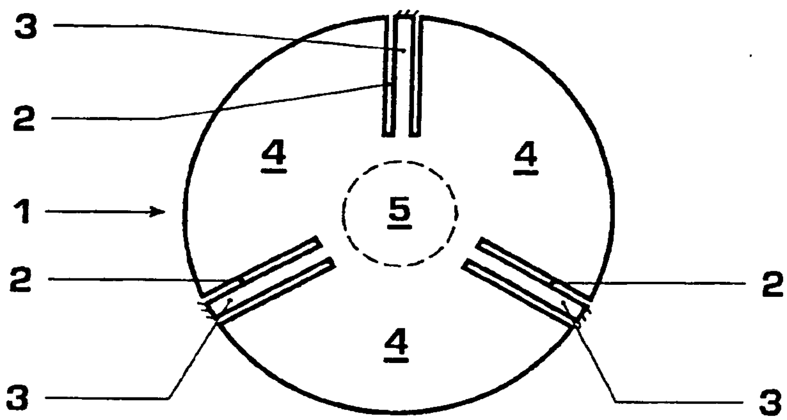

Fig. 2

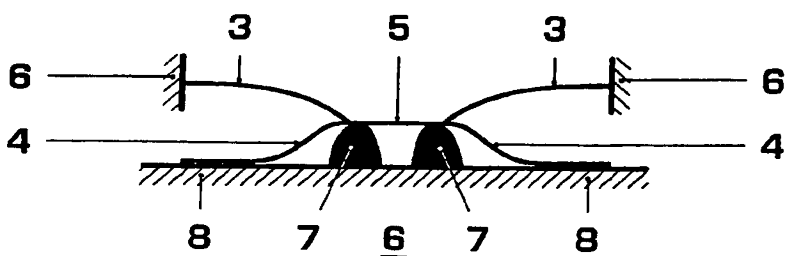

Fig. 3

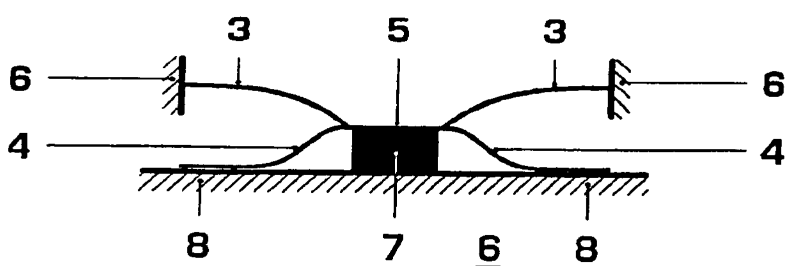

Fig. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 81 1245

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	EP 1 024 512 A (OMRON TATEISI ELECTRONICS CO) 2 August 2000 (2000-08-02) * the whole document * ---	1-10	H01H59/00
A	US 5 673 785 A (SCHLAAK HELMUT ET AL) 7 October 1997 (1997-10-07) * figures 5,6 * ---	1	
A	US 6 115 231 A (SHIRAKAWA YUKIHIKO) 5 September 2000 (2000-09-05) * figures 6-8,24-32 * -----	1	

TECHNICAL FIELDS SEARCHED (Int.Cl.7)

H01H
B81B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	14 May 2002	Overdijk, J

CATEGORY OF CITED DOCUMENTS

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